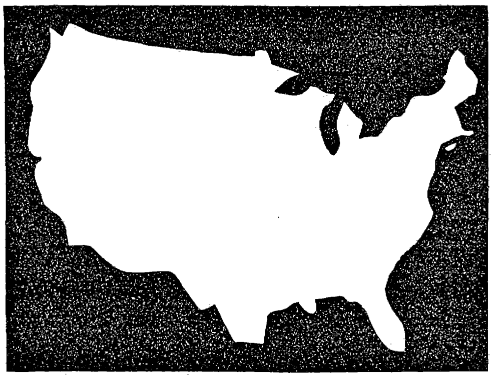
FERTILIZER USE in the UNITED STATES



Its Economic Position and Outlook

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CONTENTS

SUMMARY

General advances in farm technology will continue to increase crop yield responses to fertilizer. In 1960-64, farmers received a return of about $2.50 per dollar spent for fertilizer. At these rates, the value of product added through use of a ton of NPK was equal to the value of crops produced on 9.4 acres of cropland (acreage on which crops were harvested, plus failure and cultivated summer fallow). Thus, for the United States as a whole, as long as a ton of NPK costs less than all operating costs (including fertilizer) for 9.4 acres, alternative levels of total production could be obtained more cheaply by using more fertilizer and less land.

As fertilizer application rates are increased, other things equal, the added crop value per unit of application declines. Had rates been increased by an amount necessary to bring the added return per dollar of added fertilizer cost to $2, the 1960-64 level of crop production could have been obtained from 80 million fewer acres than the 339 million used for crops during that period.

Projected 1980 crop production needs would require about 450 million acres to be used for crops at the 1960-64 average level of technology. This acreage need would be progressively reduced to the extent that crop production per acre is increased through further substitution of technology (including fertilizer) for land. This report suggests alternative combinations of fertilizer and land for projected 1980 crop production needs, over a range of possible levels of crop production per acre.

Currently, projected crop production needs are based on commercial domestic and foreign demand expectation and little change in Government distribution programs. Changes in normal commercial demand or in Government programs would alter the estimates of resource requirements for 1980 needs as presented in this report.

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FERTILIZER USE IN THE UNITED STATES

Its Economic Position and Outlook

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INTRODUCTION

This appraisal of the current and prospective use of fertilizer in the United States is made to meet requests of the fertilizer and related industries and the needs of researchers. It is a revision of an earlier publication (5). 1/ The earlier report was based on estimates of yield response of individual crops to fertilizer associated with levels of crop technology in use about 1950 (7).

Estimates of yield response to fertilizer suitable for aggregative analysis in the setting of current technology are not available. Therefore, this evaluation of the current and prospective economic position of fertilizer use is based on changes in index numbers of crop production per acre and fertilizer use per acre of cropland for 1960-64. Cropland as used in this report includes harvested, failure, and summer fallow acreages. It does not include cropland used only for pasture. The analysis is presented by regions, in terms of the three principal plant nutrient elements, nitrogen (N), phosphorus (P), and potassium (K).

CHANGES IN FERTILIZER USE AND IN CROP PRODUCTION PER ACRE

Recent changes in use of N, P, and K and in crop production per acre relative to the 1960-64 average are presented as index numbers in table 1. Rates of N per acre of cropland in the United States more than doubled during the past 10 years, and the index of crop production per acre rose from 79 to 101 (1960-64=100). Changes in rates of P and K were also substantial. Similar comparisons are shown for individual regions.

Index numbers for 1960-64 were used as the basis for estimating relationships between rates of NPK per acre and crop production per acre. 2/ Rapid changes in technology in recent years make these relationships obsolete if based on earlier periods. The index numbers of crop production per acre reflect changes in technology, use of land, managerial factors, size of farm, and weather. The only measured causative variables in the analysis are the changes in rates of NPK per acre of cropland.

1/ Underscored numbers in parentheses refer to items listed in Literature Cited, p. 23.

2/ Procedures used throughout this analysis are described in the appendix.

Table 1.--Index numbers of changes in use of N, P, K per acre of cropland and crop production per acre, by regions, United States, 1954-64

(1960-64 = 100)

Year and item	Northeast	Lake States	Corn Belt	Northern Plains	Appalachian	Southeast	Delta States	Southern Plains	Mountain	Pacific	U. S.
1954:											
N	63	38	41	24	59	53	71	22	38	52	46
P	87	61	70	42	78	69	74	43	51	56	69
K	77	61	77	40	64	52	71	44	36	54	65
Crop production	88	80	72	67	75	63	77	69	77	86	77
1955:											
N	71	47	40	27	60	56	76	24	44	59	50
P	91	69	71	49	78	68	71	48	51	60	71
K	81	66	77	43	69	54	69	50	43	59	71
Crop production	86	80	76	62	79	81	94	70	82	86	79
1956:											
N	68	47	37	25	64	59	82	29	44	61	50
P	88	70	69	45	78	75	83	53	52	64	71
K	82	70	75	47	70	61	80	53	50	63	73
Crop production	92	88	79	60	86	80	88	66	82	89	80
1957:											
N	72	56	43	31	72	68	88	37	54	69	57
P	91	78	72	50	82	81	82	56	62	66	75
K	86	75	79	50	77	69	77	55	61	69	77
Crop production	86	88	78	81	73	72	72	77	93	91	81
1958:											
N	77	65	49	41	71	73	84	48	68	76	62
P	92	80	74	51	81	85	77	55	69	72	76
K	88	79	80	47	78	76	69	59	79	79	78
Crop production	93	92	88	105	83	81	77	97	99	91	92
1959:											
N	86	79	62	56	85	78	88	49	74	83	72
P	97	88	83	63	90	89	86	59	77	78	84
K	94	90	87	63	89	82	83	64	79	85	88
Crop production	95	93	89	81	84	81	95	93	97	97	89
1960:											
N	87	73	64	61	82	85	95	58	79	86	75
P	96	88	82	70	89	91	92	65	88	90	85
K	94	85	85	70	88	87	93	66	82	92	87
Crop production	101	95	93	105	88	89	92	100	98	94	95
1961:											
N	90	91	78	94	87	92	94	68	94	89	86
P	96	93	87	87	95	98	91	76	97	93	91
K	95	94	85	90	93	96	92	74	107	86	91
Crop production	106	102	99	92	94	101	96	105	98	93	99
1962:											
N	97	97	94	102	101	104	99	102	101	100	99
P	100	95	97	101	104	104	99	107	96	103	100
K	99	96	94	93	104	106	99	100	96	107	98
Crop production	98	101	100	107	104	98	95	97	101	104	101
1963:											
N	109	112	119	118	110	106	104	131	108	107	114
P	102	101	110	113	107	103	109	124	103	102	107
K	104	105	109	117	108	104	107	126	111	104	107
Crop production	98	105	108	100	107	104	108	97	103	103	104
1964:											
N	118	128	147	129	120	115	107	146	118	118	128
P	107	123	127	131	107	106	110	132	114	112	118
K	109	121	128	140	108	110	109	128	111	110	117
Crop production	97	97	100	96	107	108	109	101	100	106	101

Adequate measures of changes in weather as they affect crop yields for the United States as a whole are not available. But, for the Corn Belt, the calculated trend in the weather index was downward 0.7 point per year for 1960-64.3/ Hence, for that region, for 1960-64 the average increase in crop production per acre of 1.8 index points per year (calculated from data in table 1) must be attributed to changes in farm technology, including fertilizer use and factors other than weather.

CURRENT POSITION OF FERTILIZER USE

The 1960-64 average level of crop production per acre of cropland for each region and for the United States represents the base, or the index of 100 (table 2). The economic relationships indicated reflect 1960-64 average technology other than fertilizer, with fertilizer rates varying from no application to the rates estimated for highest profit per acre (economic maximum). They also reflect regional and U. S. aggregates for all crop production, based on 1960-64 average crop prices and fertilizer costs.

In the aggregate for the United States, the marginal return per dollar spent for fertilizer was $2.50 at the 1960-64 average rate of application (footnote 1, table 2). At this rate, the value of product added by use of a ton of NPK was equal to the value of crop production on 9.39 acres of cropland. At the economic maximum rate of application, the index of crop production per acre would have been 193 (1960-64=100). Similar relationships reflecting the 1960-64 fertilizer use are shown by regions, compared with rates that might have been applied.

Increasing Rates Within Changing Technology

The relationships derived do not imply that all the changes in the indexes of crop production per acre are properly attributable to changes in fertilizer use. This may be illustrated by associating the parameters of the yield equation with a technological complex reflected by yields of an earlier period, for example, 1955-57. With 1960-64=100, the index of crop production per acre for that period stands at 80.3. With this as a base, the computed index at average fertilizer use for a similar period 7 years later (1962-64) is 88.1, a gain of 7.8 points. But the actual 1962-64 index is 102.1, a gain of 21.8 points. From this, it is calculated that about 36 percent of the change in crop production per acre could be attributed solely to the increase in rates of application (7.8/21.8). The remaining 64 percent must be attributed to other factors, including changes in the general level of technology, shifts in crop production to more productive lands, weather, and complementary effects of all factors. Response to fertilizer is greatly enhanced by other improvements. This makes higher rates of application more profitable, thereby increasing the demand for fertilizer.

Other Costs and Minimum Economic Rates

Variable costs per acre exclusive of fertilizer may be used as a guide to minimum economic rates of application. For this purpose, it is necessary to regard the

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3/ Shaw and Durost (6) and unpublished data of the Economic Research Service, U. S. Department of Agriculture.

Table 2.--Specified economic relationships at different levels of use of fertilizer per acre of cropland at 1960-64 prices, by regions, United States

Region and item	Unit	1960-64 average 1/	No application	Marginal return at 1960-64 average crop and fertilizer prices: $1.00 (economic maximum)	$1.25	$1.50	$2.00	$2.50	$3.00	Maximum crop production attainable per acre (1960-64=100)
Northeast:										
N-P-K	Lb./acre	25-16-28	0-0-0	175-52-166	123-39-119	81-28-80	14-11-18	---	---	
Crop production per acre	1960-64=100	100	78	172	152	132	92	---	---	251
Substitution NPK for land 2/	Acre/ton	5.99	8.82	1.84	2.60	3.59	6.85	---	---	
Other costs per acre 3/	Dollar	34.05	30.09	91.77	64.31	48.27	32.22	---	---	
Lake States:										
N-P-K	Lb./acre	11-8-14	0-0-0	118-36-109	97-30-90	79-25-74	51-17-49	29-12-29	11-7-13	
Crop production per acre	1960-64=100	100	78	189	178	167	144	122	100	234
Substitution NPK for land 2/	Acre/ton	12.74	19.02	2.25	2.98	3.83	5.90	8.72	12.82	
Other costs per acre 3/	Dollar	13.64	11.85	70.21	51.74	38.55	24.74	17.65	13.71	
Corn Belt:										
N-P-K	Lb./acre	22-9-15	0-0-0	180-42-123	106-26-72	64-13-31	---	---	---	
Crop production per acre	1960-64=100	100	87	166	139	111	---	---	---	275
Substitution NPK for land 2/	Acre/ton	5.54	6.89	2.08	3.11	4.65	---	---	---	
Other costs per acre 3/	Dollar	33.42	31.35	66.12	46.94	36.44	---	---	---	
Northern Plains:										
N-P-K	Lb./acre	8-2-.3	0-0-0	114-21-5	102-19-4	92-17-4	77-14-3	65-12-3	55-10-2	
Crop production per acre	1960-64=100	100	69	254	248	242	230	217	205	279
Substitution NPK for land 2/	Acre/ton	55.27	94.56	2.97	3.81	4.69	6.58	8.69	11.05	
Other costs per acre 3/	Dollar	2.63	2.20	55.51	41.67	32.65	21.80	15.62	11.83	
Appalachian:										
N-P-K	Lb./acre	8-20-41	0-0-0	337-97-232	274-80-191	222-67-158	141-45-105	78-28-64	26-14-30	
Crop production per acre	1960-64=100	100	66	211	196	181	151	121	91	271
Substitution NPK for land 2/	Acre/ton	6.30	11.52	1.05	1.41	1.84	2.94	4.58	7.32	
Other costs per acre 3/	Dollar	29.86	23.89	156.02	107.34	77.69	45.63	30.61	23.41	
Southeast:										
N-P-K	Lb./acre	67-26-61	0-0-0	262-76-237	179-54-162	110-36-101	2-7-5	---	---	
Crop production per acre	1960-64=100	100	73	153	133	114	75	---	---	230
Substitution NPK for land 2/	Acre/ton	3.19	5.32	1.25	1.78	2.50	5.04	---	---	
Other costs per acre 3/	Dollar	53.71	43.19	117.75	83.05	63.10	43.69	---	---	
Delta States:										
N-P-K	Lb./acre	41-8-16	0-0-0	236-40-136	208-35-119	186-31-106	150-26-84	122-21-67	100-17-54	
Crop production per acre	1960-64=100	100	60	193	187	181	169	157	145	217
Substitution NPK for land 2/	Acre/ton	10.72	24.12	1.14	1.47	1.83	2.61	3.51	4.57	
Other costs per acre 3/	Dollar	12.44	8.84	142.31	105.68	81.88	53.65	39.48	28.05	
Southern Plains:										
N-P-K	Lb./acre	18-5-2	0-0-0	214-35-40	168-28-31	130-22-24	70-12-13	24-5-4	---	
Crop production per acre	1960-64=100	100	87	187	173	159	132	105	---	241
Substitution NPK for land 2/	Acre/ton	10.14	12.70	2.10	2.84	3.70	5.95	9.39	---	
Other costs per acre 3/	Dollar	17.41	16.07	67.40	48.64	37.09	24.35	18.13	---	
Mountain:										
N-P-K	Lb./acre	9-3-03	0-0-0	133-22-4	115-19-3	100-16-3	76-13-2	57-10-2	42-8-1	
Crop production per acre	1960-64=100	100	81	207	199	192	176	161	145	238
Substitution NPK for land 2/	Acre/ton	28.18	36.74	3.06	3.97	4.96	7.19	9.86	13.11	
Other costs per acre 3/	Dollar	7.46	6.57	64.08	47.42	36.75	24.17	17.27	13.09	
Pacific:										
N-P-K	Lb./acre	44-7-4	0-0-0	424-75-49	366-65-42	319-56-36	245-43-28	189-33-21	140-24-16	
Crop production per acre	1960-64=100	100	74	211	203	195	178	162	145	244
Substitution NPK for land 2/	Acre/ton	8.64	13.73	1.06	1.22	1.53	2.21	3.05	4.08	
Other costs per acre 3/	Dollar	22.49	18.51	201.44	148.17	114.18	74.17	52.30	39.16	
United States:										
N-P-K	Lb./acre	20-7-11	0-0-0	195-43-105	153-34-82	118-27-63	63-16-34	21-7-12	---	
Crop production per acre	1960-64=100	100	80	193	178	162	131	100	---	256
Substitution NPK for land 2/	Acre/ton	9.39	13.19	1.94	2.64	3.47	5.74	9.42	---	
Other costs per acre 3/	Dollar	19.53	17.32	78.01	55.39	41.57	26.59	19.51	---	

1/ The marginal return per dollar cost of fertilizer at 1960-64 average rates, by regions, is: N.E. $1.90; L.St. $2.99; C.B. $1.60; N.Pl. $7.30; App. $2.85: S.E. $1.68; Delta $4.86; S.Pl. $2.58; Mt. $4.45; Pac. $4.37; U.S. $2.50.
2/ Acres required to produce crops equal in value to the value of the product added through use of a ton of NPK applied at the indicated rates.
3/ Variable costs (excl. fertilizer) at which use of the indicated rates of NPK would result in equalizing marginal returns to all variable inputs--that is, minimum cost per unit of aggregate crop production would result from use of the indicated rates if other costs were at these levels.

other variable costs as a fixed bundle in the production situation for which a particular curve describes the yield response. In contrast, fertilizer expenditures per acre are regarded as the only flexible input.

The minimum economic rate is important when there is any limitation on capital to meet variable (operating) costs, or any restriction on crop production. This is the rate at which the return per dollar cost of all inputs is the same. Highest returns per dollar invested in all variable inputs, as well as on any specified volume of crop production, are obtained at this rate of application. Thus in the aggregate, as well as for individual farmers, it is important to find the combination of technology and land that will maximize returns to limited capital and maximize profit on limited production when there is a restriction on either.

Costs per acre exclusive of fertilizer at which different rates of application would be the economic minimum are shown in table 2. For example, at a marginal return of $2 per dollar spent for fertilizer, 63-16-34 pounds of NPK would be the economic minimum application for the United States if variable costs exclusive of fertilizer were $26.59 per acre. The cost of the fertilizer would be about $13 per acre. This is shown graphically in figure 1, which also shows the economic minimum expenditures for fertilizer at different levels of other operating costs.

With other costs at $26.59, a fertilizer cost of $13 would increase total variable costs to $39.59 per acre. Thus, if only $1,000 is available to meet operating costs, the optimum acreage would be 25.26 acres ($1,000/$39.59). Highest profit on $1,000 would be obtained from this acreage. In such a situation, it would be more profitable to leave some land idle than to apply less fertilizer in order to use all the land.

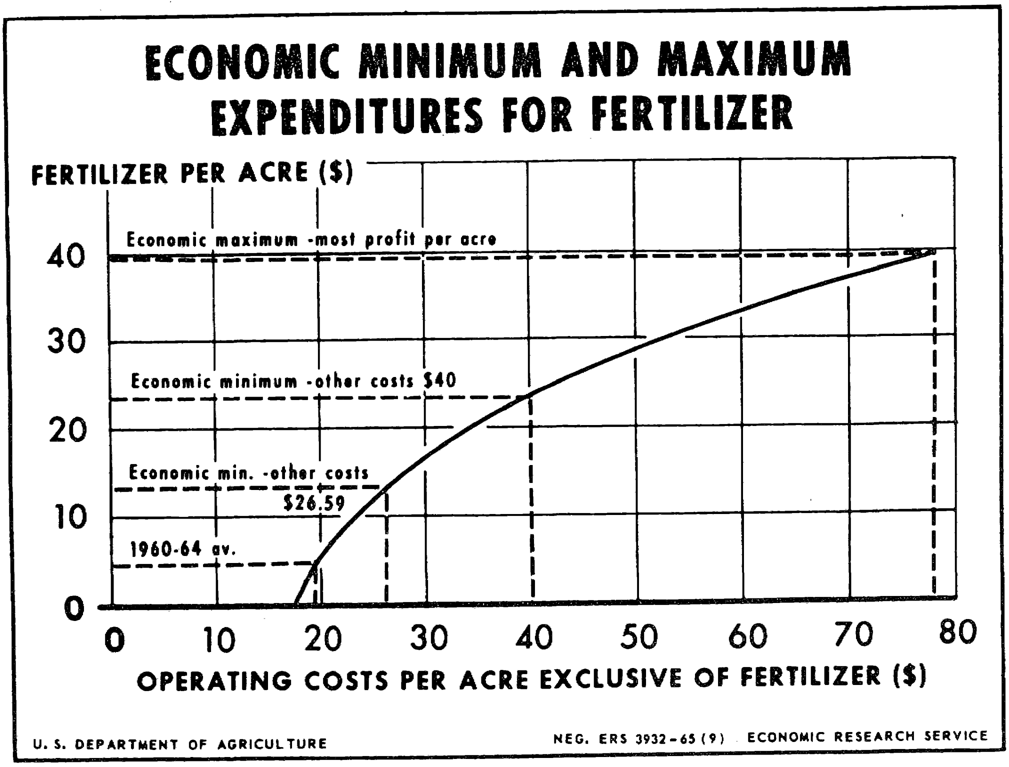


Figure 1

But the level of operating costs exclusive of fertilizer, rather than the extent to which capital is limited, determines the economic minimum rate of application. In a particular situation the other costs are not affected by the rate of application except in a limited way. Instead, they influence the fertilizer input required to equalize returns on all variable costs.

A larger application of fertilizer increases yields and reduces harvesting costs per unit of product while increasing harvesting costs per acre. But between economic minimum and economic maximum levels of use, there is little additional harvesting cost per acre for most crops. Hence harvesting costs can be included when considering other costs per acre as a guide for estimating approximate economic minimum rates of application.

The curve of figure 1 stops at the point of the maximum economic rate--the rate for highest profit per acre where the return per added dollar of fertilizer cost would be only $1. Individual farmers who are able to do so would realize highest total profit from crop production by applying the maximum economic rate. The economic minimum and the economic maximum rates provide the economic limits within which farmers should operate. The farmer's evaluation of risk would largely influence the rate applied within these limits. Higher rates bring lower marginal returns. Therefore farmers can often find more profitable investments for their capital than by applying fertilizer too close to the economic maximum rates per acre.

Fertilizer-Land Substitution Relationships

A ton of NPK substitutes for the greatest number of acres at the point of no application, and for the fewest acres (within the economic range) at the economic maximum rate where the marginal return per dollar spent for fertilizer is only $1 (table 2). The reason for this is that increments in yield are higher at low rates and diminish as higher rates are applied. A relationship also exists between other costs associated with economic minimum rates of application and the acreage for which a ton of NPK substitutes. The level of other costs determines the point on the fertilizer-yield response curve at which marginal returns to all variable inputs are equalized. As these costs rise, the economic minimum rate also rises so that both increments in yield and fertilizer-land substitution relationships progressively decline.

Costs per acre other than fertilizer are substantially the same irrespective of the rate of application. These costs may sometimes exceed gross returns per acre at the point of no application. Hence, some fertilizer is needed in order to break even. At the break-even point, increments in yield are high, but decline as higher rates increase the return per acre over fertilizer cost. Finally, at the economic maximum rate, at which returns per dollar to all variable inputs would be $1, other costs would equal gross return less fertilizer cost. If other costs were at that level, there would be no profit.

Aggregate substitution of fertilizer for land may be illustrated by assuming one of many potential levels--for example, the rates associated with a marginal return of $2 per dollar spent for fertilizer. At this level, rates of NPK per acre of cropland are 63-16-34 pounds, respectively, for the United States as a whole (table 2). The index of crop production per acre is 131. The 1960-64 average acreage of cropland was 338.9 million acres. Therefore, the 1960-64 average crop production would have been obtained on 258.7 million acres (338.9/1.31).

Fertilizer use on the reduced acreage would have been 8.14 million tons of N, 2.07 million tons of P, and 3.10 million tons of K--a total of 13.31 million tons of NPK. Actual average use on the larger acreage was 3.43, 1.25, and 1.92 million tons, or a total of 6.60 million tons. The aggregate substitution of NPK combined for land would have been 6.71 million tons for 80.2 million acres, or 11.95 acres per ton. The 5.74 acres per ton shown at that point in table 2 is the marginal rate of substitution at the specified rates of application.

Changing Rates With Cropland Constant

The aggregate effects of applying fertilizer at or near the economic maximum rates without a corresponding reduction in acreage are obvious. Farmers in 1960-64 received a return of $2.50 per dollar spent for fertilizer. If, in the aggregate for the United States, they had fertilized only to the point of a $2 marginal return, crop production would have been 31 percent above the 1960-64 average (table 2). A shift of this magnitude does not occur in 1 or 2 years because all farmers are not able to make such drastic changes in a short period. But the limitations have to do with individual and institutional factors, rather than with the physical input-output relationships that are now being experienced by leading farmers. With the continuing trend to larger farms and greater availability of capital and managerial skills among farmers, more rapid rates of adoption can be expected in the future.

One study has indicated that the 1955-57 average crop production under price and control programs exceeded by about 9 percent what would have cleared a free market at that time (1, p. 93). This study also indicates that prices would have fallen by 20 percent if average crop production in that period had been marketed without support programs. This would be a reduction of more than 2 percent in price for each 1-percent increase in crop production.

PROJECTING FERTILIZER AND CROPLAND NEEDS

Potential crop production from increased use of fertilizer exceeds projected U.S. crop production needs based on current estimates of population growth and price relationships. Such estimates of needs are below levels that would be required if our production potential were to be drawn on to supply healthful diets to overpopulated, underdeveloped countries. For this report, projected crop production needs for 1980--which are based on commercial, domestic, and foreign demand expectations and little change in Government distribution programs (domestic and foreign)--are used as the basis for projections of fertilizer use and cropland acreage (2).

Regional Distribution of U.S. Crop Production

As the analysis is presented by regions, recent changes were noted in the proportion of total crop production by regions. The percentage of U.S. crop production, by regions, was established for each of five 5-year periods, beginning with 1939-43. A trend, by regions, was established and the percentage of U.S. crop production was estimated for each region for 1979-83 (table 3).

Table 3.--Percentage of U.S. crop production by regions, average 1960-64 and projected 1979-83

Region	Percentage of total production		Change in total production
	Average 1960-64	Projected 1979-83	
	Percent	Percent	Percent
Northeast	6.00	4.85	-1.15
Lake States	8.90	8.00	- .90
Corn Belt	22.60	24.00	1.40
Northern Plains	11.40	10.25	-1.15
Appalachian	9.60	9.20	- .40
Southeast	7.60	7.47	- .13
Delta States	6.10	5.75	- .35
Southern Plains	8.80	8.39	- .41
Mountain	6.70	7.33	.63
Pacific	12.30	14.76	2.46
United States	100.00	100.00	---

Alternative Levels of Crop Production Per Acre

Technological breakthroughs have foretold, in large measure, the substantial increases in yields of recent years. But the recent, more rapid rate of adoption of known technology has also been important. This trend will likely continue. New developments tend to offset the adverse effects of less favorable seasons on yields. These factors, together with improved plant breeding and other advances expected within a few years, could render quite conservative any yield projections made now. This has occurred for most of the 1975 projections of individual crop yields that were made a few years ago.

No specific projections of crop production per acre were made in this report. Instead, a series of estimated indexes of crop production per acre was presented, by regions, and for the United States with the 1960-64 average = 100. Also, the acreage requirement to meet 1980 projected crop production needs at 1960-64 average technology was calculated. This base acreage requirement, divided by any selected estimate of crop production per acre, resulted in an estimate of the cropland acreage for meeting projected 1980 crop production needs at that level of crop production per acre.

Alternative Combinations of Cropland and Fertilizer

Indexes of rates of N per acre associated with each of a series of indexes of crop production per acre were calculated. The tonnage of N was calculated for each of the acreage requirements for meeting projected 1980 crop production needs at different indexes of crop production per acre. Tonnages of P and K were then calculated using estimated ratios of P and K to N as described in the next section of the report. This provided estimates of tonnages of each nutrient associated with the cropland acreage requirement at different indexes of crop production per acre. These estimates for the United States and for each region are presented in table 4, and were used in constructing figures 2 to 12. These curves permit individual projections of crop production per acre, corresponding cropland acreages, and quantities of NPK for meeting projected 1980 crop production needs.

Projected Nutrient Ratios

Ratios of P and K to N occurring in recent years were studied in the light of changes that would be expected if based on time trends or on the overall removal of N, P, and K in harvested crops. The ratio in 1964 was 1 to 0.335 to 0.512 for N, P, and K, respectively, for the United States as a whole. Projecting a time trend from the early 1950's to 1980 would result in an NPK ratio of 1 to 0.19 to 0.33. The ratio of N, P, and K in harvested crops has been calculated as 1 to 0.14 to 0.48 when no allowance is made for accumulations in crop residues, or additions through use of legume crops. When these are taken into account, the ratio becomes 1-0.21-0.71(3).[4/] However, much of the K reflected by the latter ratio occurs in dryland areas where soils are high in this element and where little or none of it is added through use of fertilizers.

General information on relative yield response and prospective changes in price relationships between the three principal nutrients were considered in estimating future nutrient ratios. The estimated 1980 NPK ratio at the U.S. level at an index of crop production per acre of 200 is approximately 1 to 0.22 to 0.52. Differences among regions were estimated on a judgment basis. The projected ratios of P and K to N are slightly higher at the intermediate indexes of crop production per acre.[5/]

Costs of Principal Plant Nutrients

Current costs per pound of N, P, and K to farmers, by regions, were estimated on the basis of reported distribution and reported prices paid for different materials and mixtures (table 5). Some unpublished prices were obtained through contact with individuals.

4/ To convert P to P_2O_5, multiply by 2.29137; from K to K_2O, multiply by 1.20459.

5/ The assistance of George H. Enfield, Assistant Director of the Division of Science, Technology and Management, Federal Extension Service; John N. Mahan, Fertilizer Specialist, Agricultural Stabilization and Conservation Service; and J. Richard Adams, Chemist, Soil and Water Conservation Research Division, Agricultural Research Service, all of the U.S. Department of Agriculture, in estimating future NPK ratios, is gratefully acknowledged.

Table 4.--Estimated cropland acreages and fertilizer tonnages to meet projected 1980 crop production needs at different levels of crop production per acre, United States, by regions 1/

Index of crop production per acre 2/	Item	Unit	Northeast	Lake States	Corn Belt	Northern Plains	Appalachian	Southeast	Delta States	Southern Plains	Mountain	Pacific	United States
100-------	Cropland	1,000 acres	16,098	42,472	107,712	104,417	20,784	14,653	16,715	45,282	50,320	32,311	450,764
	N	1,000 tons	150	166	896	318	297	387	254	294	173	530	3,465
	P 3/	do.	99	126	381	77	157	144	52	78	53	85	1,252
	K 4/	do.	178	224	640	13	330	346	102	39	6	53	1,931
125-------	Cropland	1,000 acres	12,878	33,977	86,170	83,534	16,627	11,722	13,372	36,226	40,256	25,849	360,611
	N	1,000 tons	367	444	2,823	548	563	709	368	921	445	990	8,178
	P 3/	do.	142	184	751	114	213	227	68	170	89	168	2,127
	K 4/	do.	370	455	1,942	22	476	649	181	163	13	108	4,379
150-------	Cropland	1,000 acres	10,732	28,315	71,808	69,611	13,856	9,769	11,143	30,188	33,546	21,541	300,509
	N	1,000 tons	551	690	4,409	739	785	1,020	479	1,468	683	1,394	12,218
	P 3/	do.	181	239	1,062	145	261	303	85	252	123	242	2,893
	K 4/	do.	535	662	3,014	30	601	925	255	271	19	156	6,468
175-------	Cropland	1,000 acres	9,199	24,269	61,550	59,667	11,877	8,373	9,551	25,896	28,754	18,463	257,579
	N	1,000 tons	735	947	5,907	919	994	1,357	608	2,034	932	1,809	16,242
	P 3/	do.	222	301	1,362	175	310	388	105	338	158	353	3,712
	K 4/	do.	701	884	4,027	37	725	1,223	337	381	26	205	8,546
200-------	Cropland	1,000 acres	8,049	21,236	53,856	52,209	10,392	7,327	8,357	22,641	25,160	16,155	225,382
	N	1,000 tons	949	1,277	7,519	1,110	1,219	1,798	792	2,739	1,243	2,308	20,954
	P 3/	do.	272	383	1,690	208	364	502	134	446	204	406	4,609
	K 4/	do.	895	1,171	5,119	46	861	1,616	451	518	34	264	10,975

1/ Harvested, plus failure, plus cultivated summer fallow.
2/ 1960-64 = 100.
3/ To convert to P_2O_5 multiply by 2.29137.
4/ To convert to K_2O multiply by 1.20459.

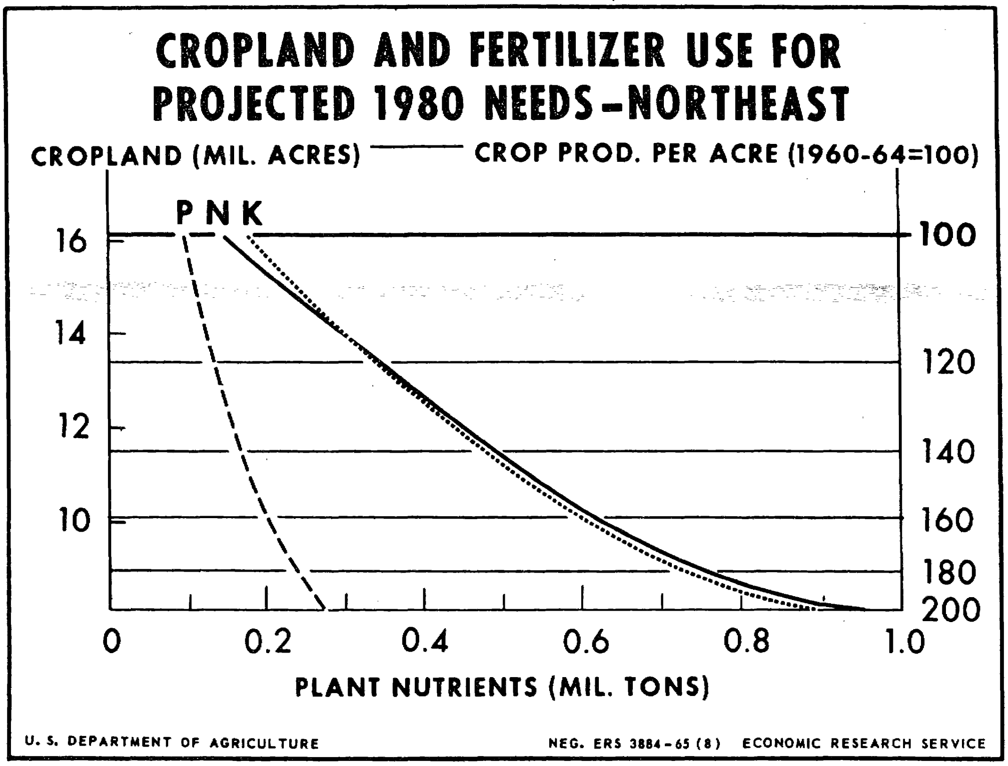


Figure 2

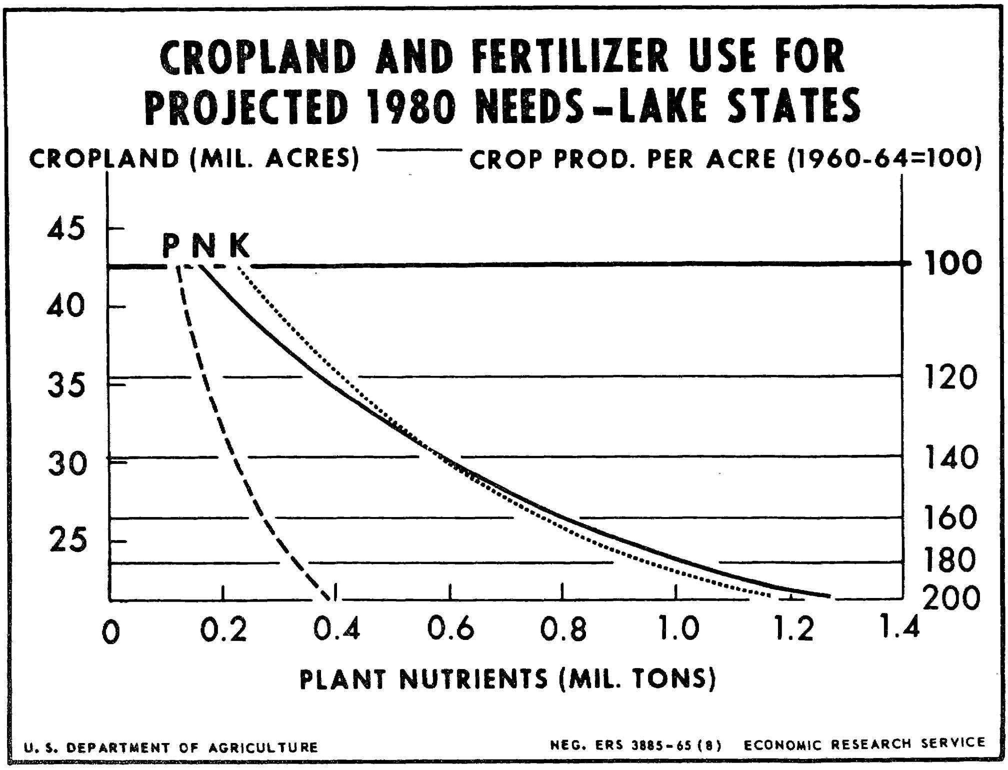


Figure 3

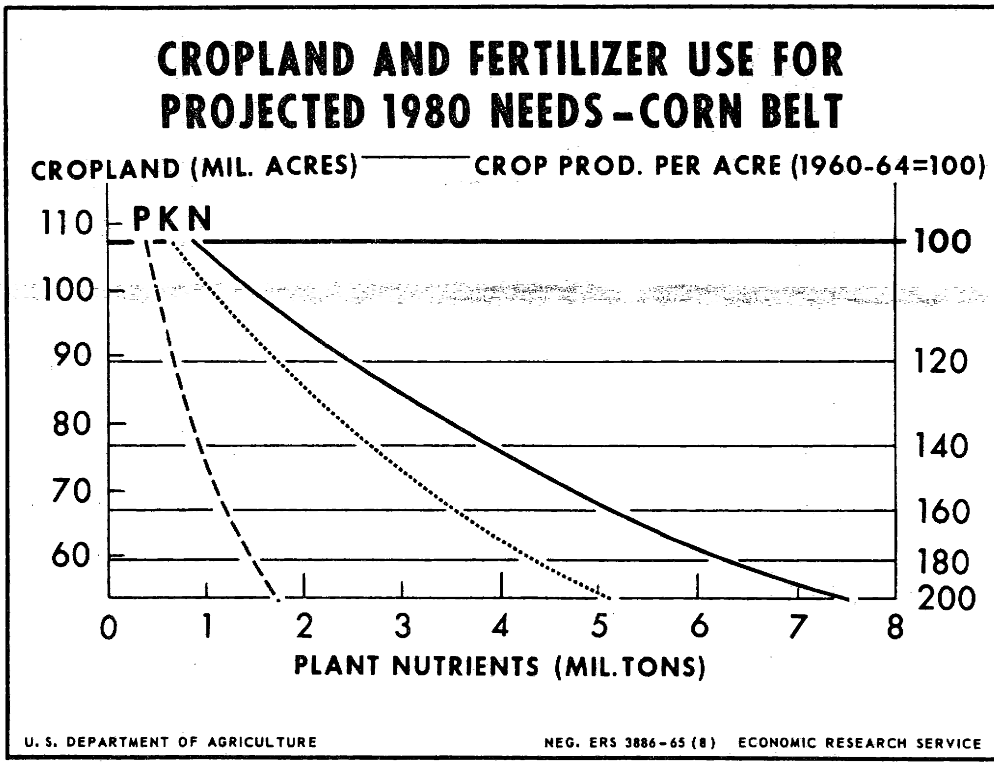
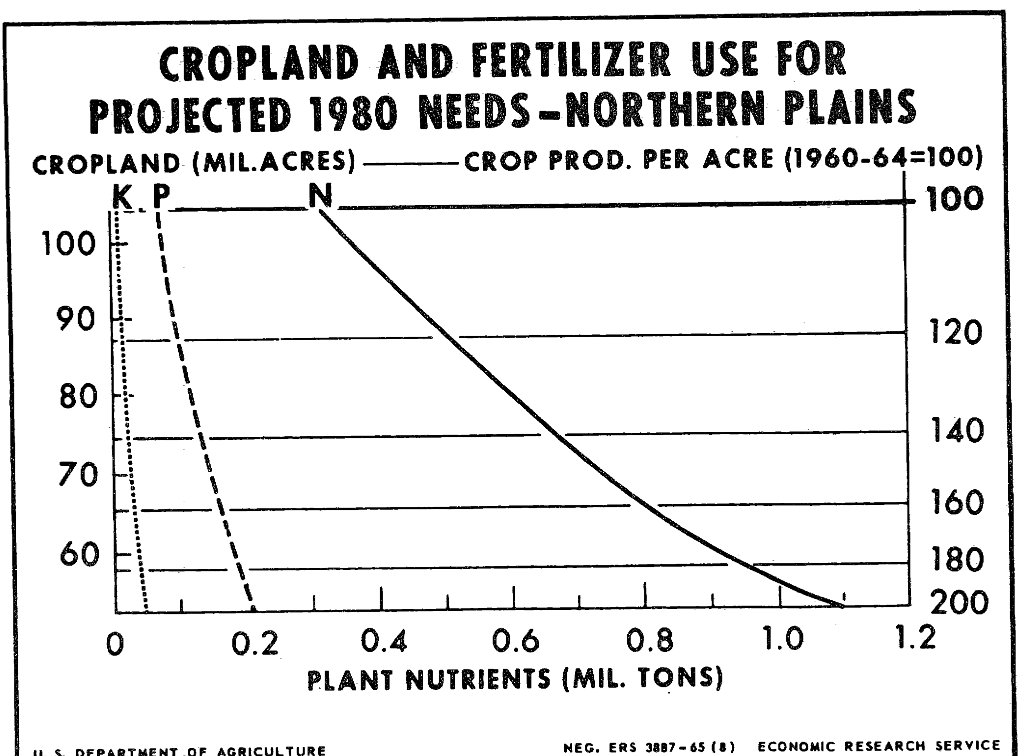


Figure 4



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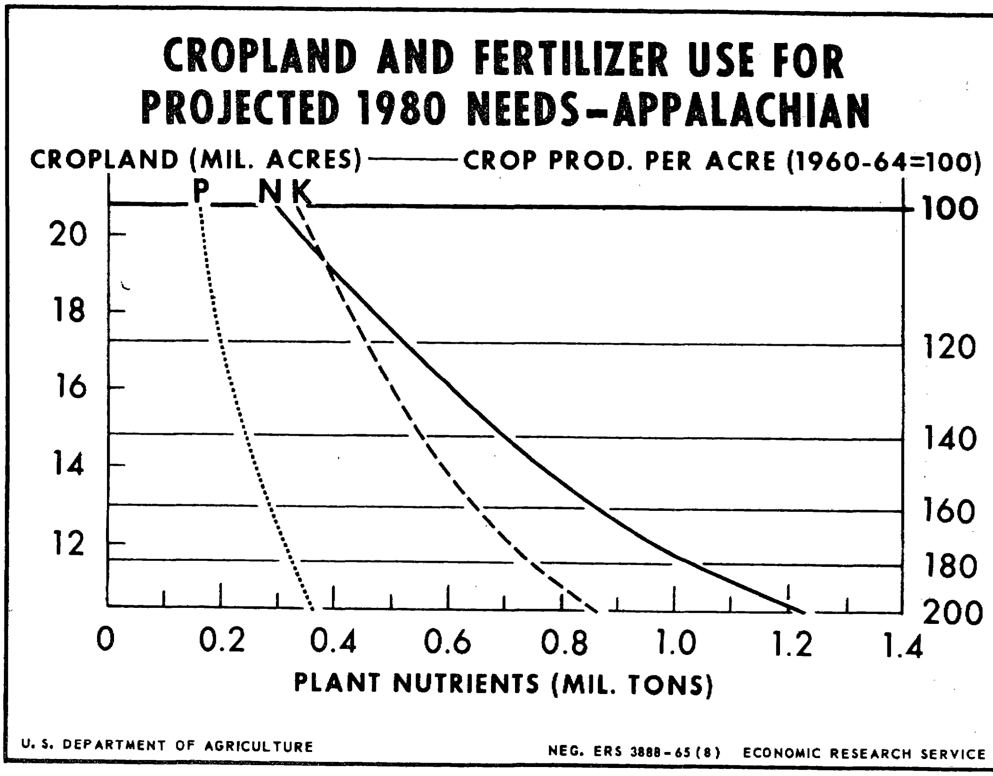

Figure 6

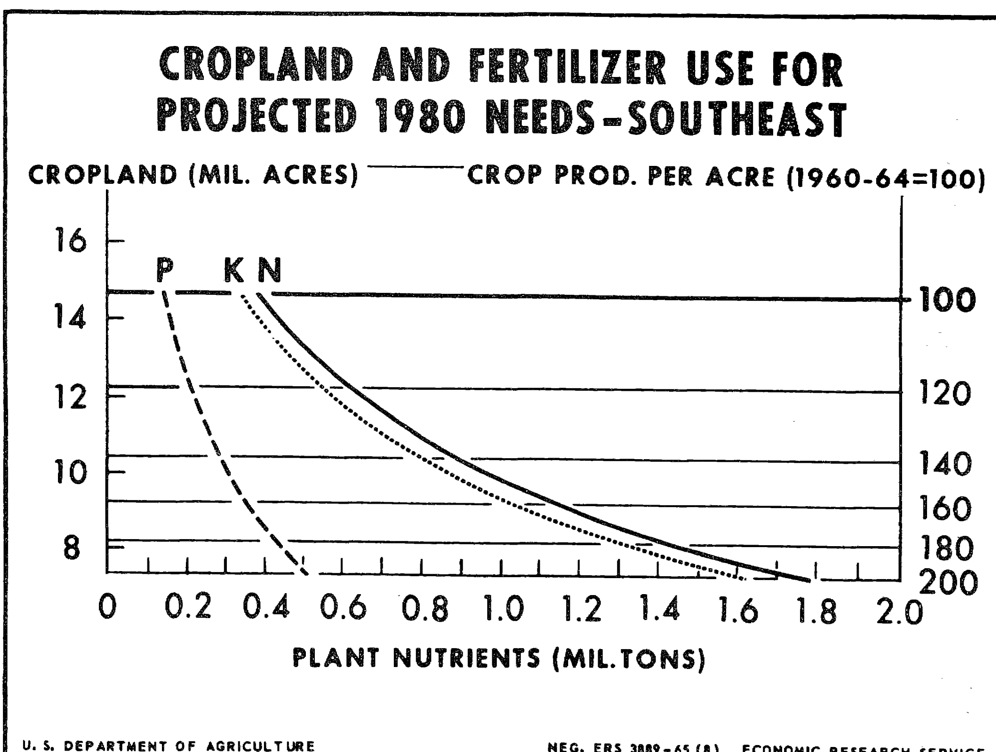

Figure 7

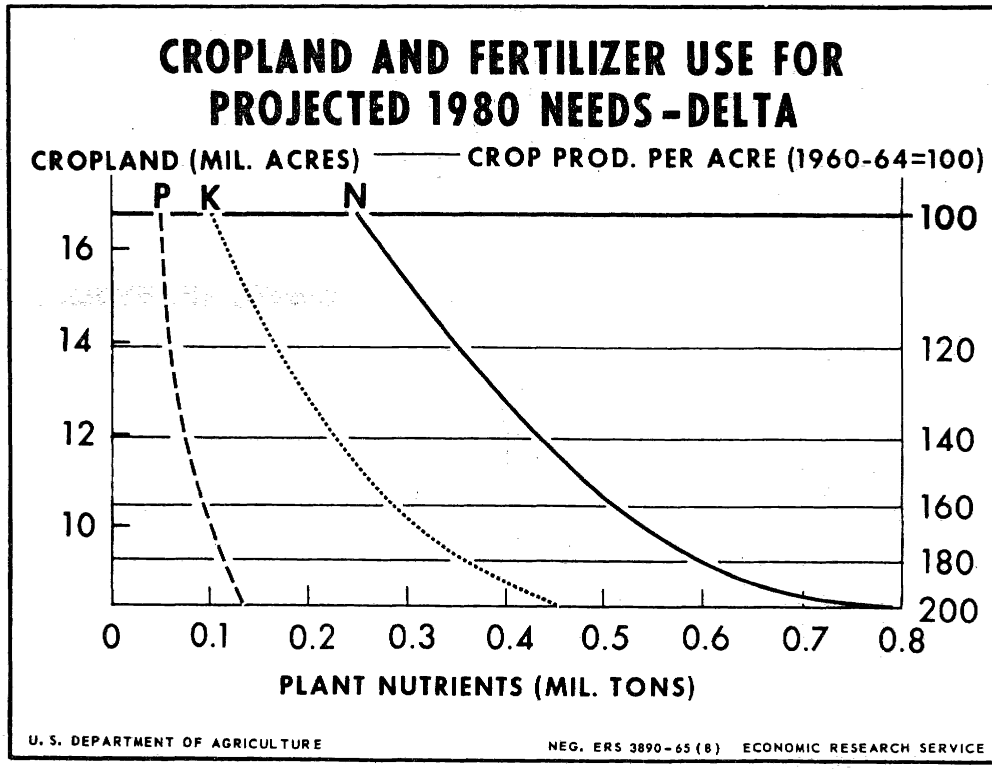

Figure 8

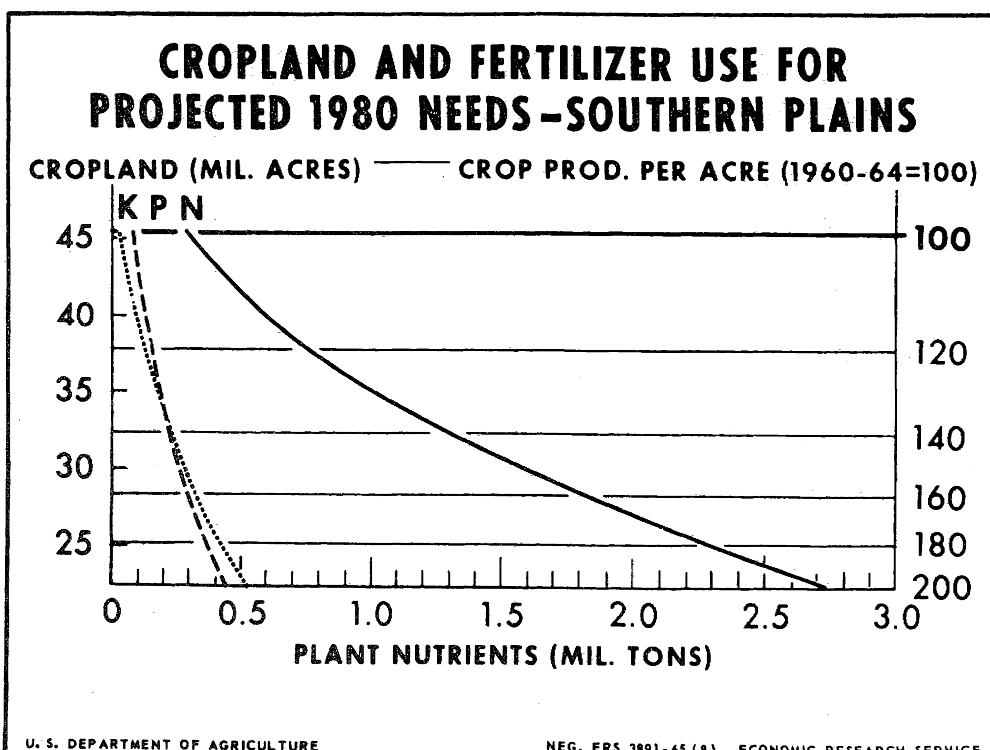

Figure 9

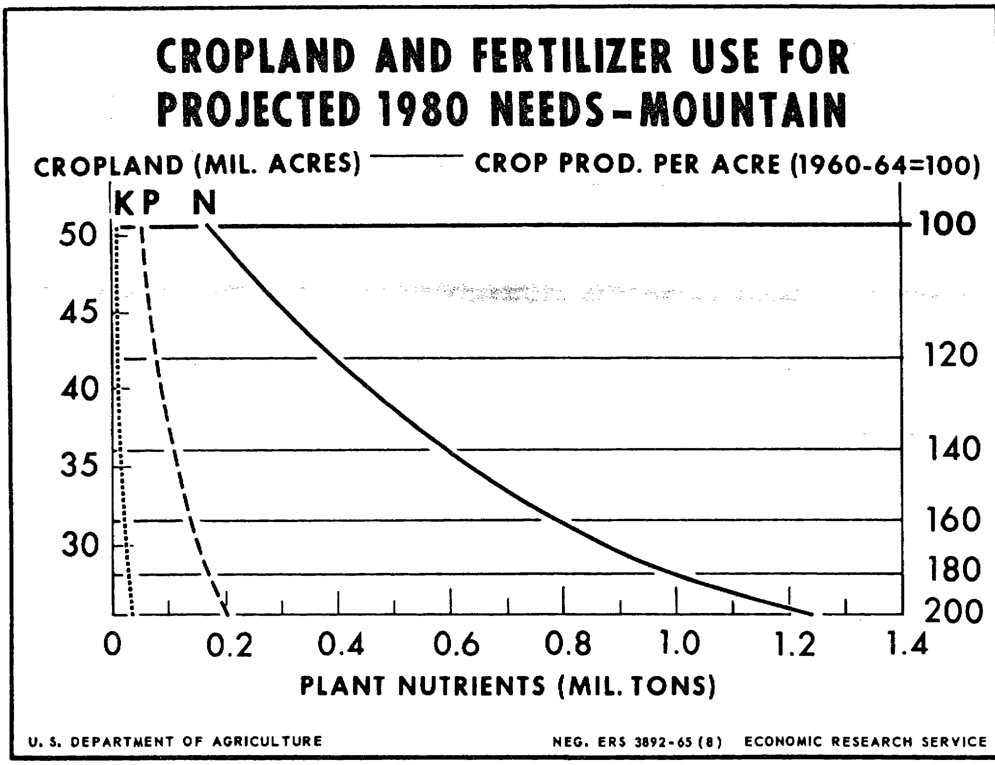

Figure 10

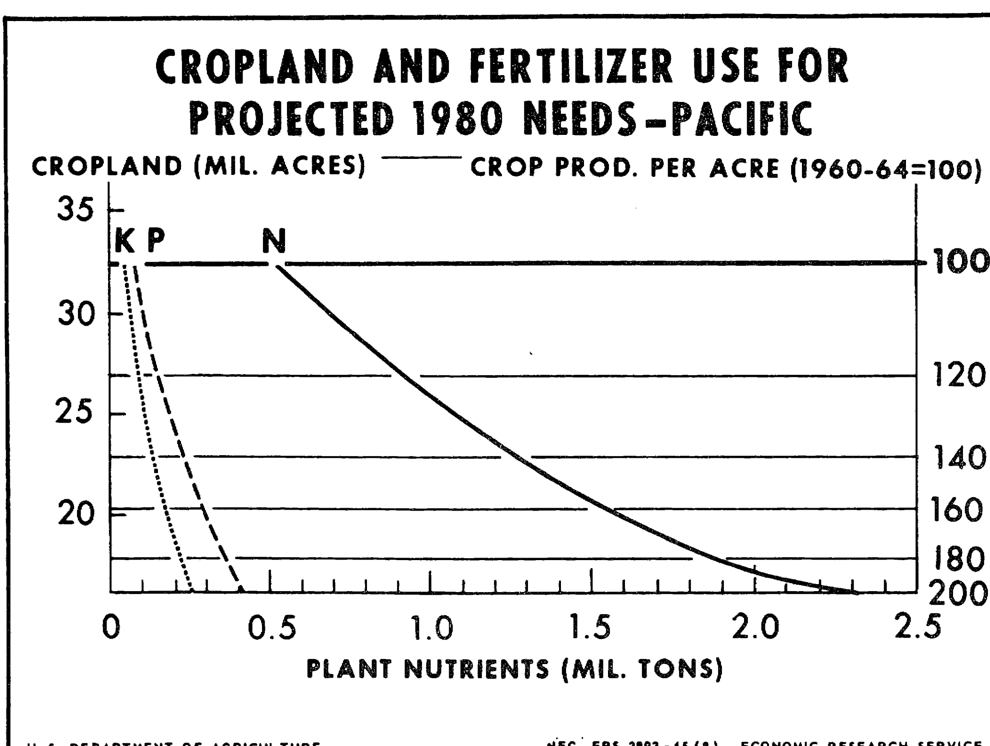

Figure 11

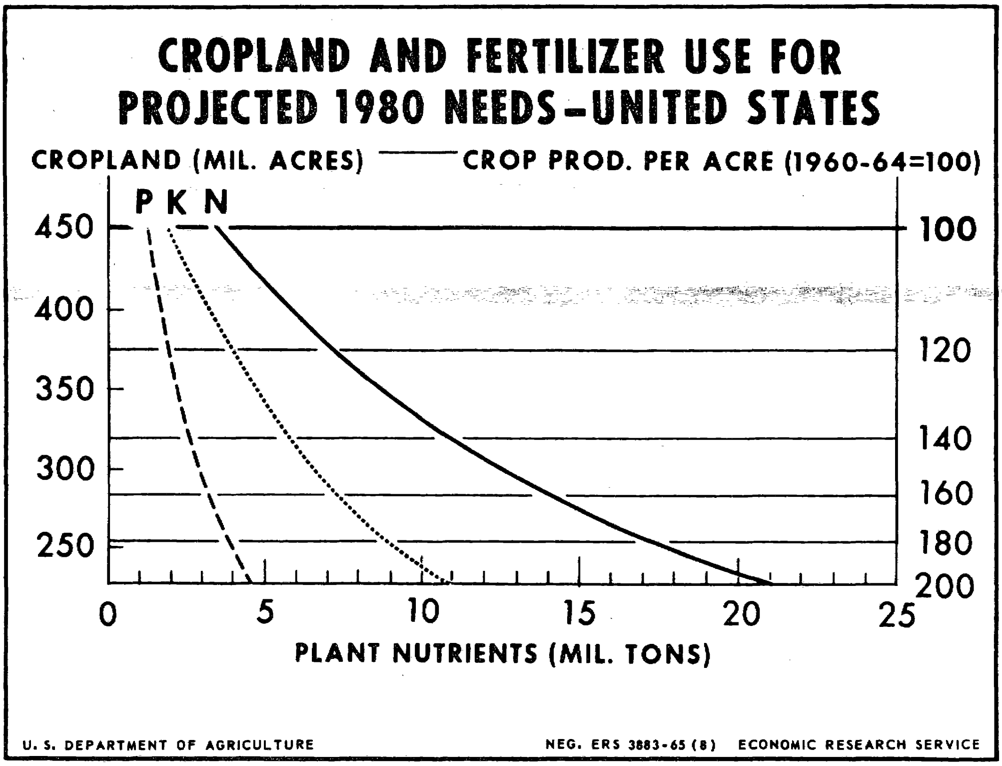

Figure 12

The estimates are intended to indicate a weighted average cost per pound of each nutrient, taking into account the relative quantity of single nutrient materials for direct application, and the different grades of mixed materials. Costs per pound of N, P, and K in materials carrying only one of these nutrients are easily determined, as is the average cost per pound of all nutrients combined in mixtures. The relative cost per pound of N, P, and K in single nutrient materials was applied to the average cost per pound of all nutrients in mixtures to estimate the cost per pound of each nutrient in mixtures. The weighted average cost per pound of each nutrient in materials and mixtures combined is the estimated current price.

Projected 1980 prices anticipate substantial reductions in costs per pound of N, a 15-percent reduction in costs per pound of K, and shifts from current patterns of use toward a higher proportion of materials that supply the nutrients at lower costs per pound. Principal shifts expected by 1980 are substitution of ammonium nitrate, anhydrous ammonia, or solutions for sodium nitrate where it is currently used. Also a continued trend toward substitution of lower cost materials for other solid nitrogen mixtures and materials should reduce costs of N relative to crop prices and costs of other farm inputs.

For N, price reductions occurring in recent years for the United States as a whole were projected to 1980, with regional differentials assumed to be the same as at present. Continuation of this reduction would seem to be supported by existing and potential ammonia plant capacity, and the greatly reduced manufacturing costs.

Table 5.--Estimated current and projected prices per pound of principal plant nutrients, by region, United States

Region	Prices per pound for--					
	N		P		K	
	Estimated current	Projected 1980	Estimated current	Projected 1980	Estimated current	Projected 1980
	Dollars	Dollars	Dollars	Dollars	Dollars	Dollars
Northeast	0.145	0.066	0.281	0.183	0.084	0.071
Lake States	.119	.056	.237	.186	.073	.062
Corn Belt	.113	.053	.228	.185	.066	.056
Northern Plains	.090	.045	.194	.161	.074	.053
Appalachian	.145	.057	.247	.187	.087	.074
Southeast	.139	.051	.177	.148	.064	.054
Delta States	.115	.049	.217	.186	.070	.060
Southern Plains	.093	.046	.210	.181	.070	.060
Mountain	.119	.058	.213	.206	.068	.058
Pacific	.113	.055	.251	.204	.068	.058
United States	.116	.051	.230	.192	.070	.060

The projected prices also assume an effective competition in the industry, and a cost structure throughout the manufacturing, transporting, and retailing segments of the industry that will permit continued improvements and economies to be reflected in lower costs to farmers.

Development of the large Canadian deposits of potash and technological gains in extracting it may justify the projected 15-percent reduction in cost per pound of K. For P, the projected reduced prices stem from a projected substitution of ammonium phosphates for normal superphosphate. No reduction in cost per pound of a particular product carrying P is anticipated.

Effect of Projected Price Changes

The items of analysis shown in table 2, based on current prices, are repeated in table 6, based on projected prices. Table 6 reflects crop prices used in developing 1980 projected crop production needs (3).

The economic analysis presented in tables 2 and 6 is based on simultaneous changes in rates of N, P, and K with changes in the index of crop production per acre. The projected ratios of P and K to N predetermine a fixed pattern so that changes in relative costs of NPK do not influence the nutrient ratios at different levels of application. In the aggregative approach used, it is not possible to measure the yield effect of each nutrient separately, as when analyzing an experiment where each nutrient is varied independently of the others. But comparison of tables 2 and 6 does show the effect of the changed price-cost relationship on rates, substitution relationships, and indexes of crop production per acre associated with the same levels of marginal return to fertilizer.

For the United States as a whole, projected price changes would result in a 40-percent increase in rates per acre at the economic maximum level of crop production per acre, compared with current prices. At that level, the index of crop production per acre at projected prices would be 213, compared with 193 at current prices. The estimated maximum attainable index of crop production per acre is 256, 1960-64=100 (table 2).

Expenditures for Fertilizer

Expenditures for fertilizer to meet 1980 projected crop production needs at different rates of marginal return to fertilizer at current and projected prices are shown by regions in table 7. For any specified marginal return per dollar cost of fertilizer, the lower projected fertilizer prices would mean a lower total expenditure, even though the effect of lower prices is to increase rates per acre. The increase in rates per acre results in fewer acres needed to meet projected needs at any level of marginal return to fertilizer. However, the effect of projected lower crop prices is to reduce rates of application at any level of marginal return to fertilizer.

Occasionally, the combined effect of projected crop and fertilizer prices is to increase the fertilizer expenditure for 1980 needs at the same rate of marginal return to fertilizer. An example of this is the Corn Belt at the marginal return of $1.50 per dollar spent for fertilizer. Here, the estimated yield response is such that at projected prices the rate of NPK per acre is more than 2-1/2 times that at current prices. This is more than sufficient to offset the lower acreage requirement.

Table 6.--Specified economic relationships at different levels of use of fertilizer per acre of cropland, at projected prices, by regions, United States

Region and item	Unit	Marginal returns at projected crop prices and fertilizer costs								No fertilizer used
		$1.00 (Economic maximum)	$1.25	$1.50	$2.00	$2.50	$3.00	$3.50	$6.00	
Northeast:										
N-P-K	Lb./acre	262-74-246	210-75-199	168-50-160	101-33-98	49-20-50	7 - 9 - 11	---	---	0-0-0
Crop production per acre	1960-64=100	196	183	169	142	114	87	---	---	78
Substitution NPK for land 1/	Acre/ton	1.10	1.48	1.92	3.06	4.74	7.49	---	---	8.86
Other costs per acre 2/	Dollar	99.66	68.44	53.32	33.65	23.95	18.84	---	---	18.45
Lake States:										
N-P-K	Lb./acre	147-43-134	125-38-115	108-33-99	79-25-74	58-72-55	40-15-39	25-10-26	---	0-0-0
Crop production per acre	1960-64=100	201	192	184	167	151	134	117	---	78
Substitution NPK for land 1/	Acre/ton	1.58	2.06	2.59	3.79	5.27	7.11	9.48	---	19.00
Other costs per acre 2/	Dollar	69.83	51.10	39.48	25.66	18.10	13.65	10.83	---	7.86
Corn Belt:										
N-P-K	Lb./acre	296-66-201	209-48-143	148-35-101	52-15-36	---	---	---	---	0-0-0
Crop production per acre	1960-64=100	195	175	155	115	---	---	----	---	87
Substitution NPK for land 1/	Acre/ton	1.30	1.81	2.42	4.42	---	---	---	---	6.88
Other costs per acre 2/	Dollar	67.05	48.32	36.28	23.84	---	---	---	---	20.12
Northern Plains:										
N-P-K	Lb./acre	136-25-6	124-23-5	115-21-5	99-18-4	88-16-4	78-14-3	70-13-3	41-8-2	0-0-0
Crop production per acre	1960-64=100	263	259	255	247	238	230	222	182	69
Substitution NPK for land 1/	Acre/ton	1.89	2.40	2.92	4.03	5.20	6.46	7.81	16.33	94.76
Other costs per acre 2/	Dollar	55.75	42.60	33.98	23.43	17.32	13.36	10.64	4.47	1.32
Appalachian:										
N-P-K	Lb./acre	462-131-313	399-114-272	347-100-239	266-78-186	202-61-145	151-48-111	107-36-83	---	0-0-0
Crop production per acre	1960-64=100	232	223	213	194	174	155	137	---	66
Substitution NPK for land 1/	Acre/ton	.61	.80	1.00	1.47	2.04	2.76	3.68	---	11.28
Other costs per acre 2/	Dollar	190.43	138.37	105.28	66.54	45.51	32.97	25.07	---	14.38
Southeast:										
N-P-K	Lb./acre	503-140-452	419-118-377	350-100-316	247-71-220	159-49-145	91-31-84	33-15-32	---	0-0-0
Crop production per acre	1960-64=100	189	179	169	148	128	108	86	---	73
Substitution NPK for land 1/	Acre/ton	.53	.70	.89	1.35	1.96	2.79	4.01	---	5.31
Other costs per acre 2/	Dollar	172.53	124.98	95.03	60.51	42.81	32.62	26.59	---	24.33
Delta States:										
N-P-K	Lb./acre	287-48-167	259-44-150	237-40-136	201-34-115	173-29-98	151-26-85	132-23-73	65-12-33	0-0-0
Crop production per acre	1960-64=100	201	198	194	186	178	170	162	121	60
Substitution NPK for land 1/	Acre/ton	.72	.92	1.13	1.57	2.05	2.58	3.16	7.19	23.69
Other costs per acre 2/	Dollar	147.49	111.74	88.37	60.04	43.76	33.38	26.32	10.85	5.51
Southern Plains:										
N-P-K	Lb./acre	284-46-54	238-39-45	201-33-38	141-24-26	95-16-17	57-10-10	25-5-4	---	0-0-0
Crop production per acre	1960-64=100	202	193	183	164	144	125	105	---	87
Substitution NPK for land 1/	Acre/ton	1.38	1.81	2.29	3.41	4.84	6.71	9.28	---	12.71
Other costs per acre 2/	Dollar	67.50	49.50	38.10	24.89	17.87	13.78	11.28	---	9.97
Mountain:										
N-P-K	Lb./acre	166-27-5	147-24-4	132-21-4	108-18-3	90-15-2	75-13-2	62-11-2	17-4-05	0-0-0
Crop production per acre	1960-64=100	217	212	206	196	186	175	165	112	81
Substitution NPK for land 1/	Acre/ton	1.98	2.53	3.12	4.38	5.78	7.35	9.13	23.02	39.43
Other costs per acre 2/	Dollar	63.20	47.65	37.54	25.35	18.43	14.07	11.14	4.97	3.94
Pacific:										
N-P-K	Lb./acre	531-94-61	473-84-54	426-75-49	352-62-40	294-52-34	247-43-28	207-36-24	68-11-7	0-0-0
Crop production per acre	1960-64=100	223	217	212	201	190	179	168	113	74
Substitution NPK for land 1/	Acre/ton	.59	.75	.93	1.31	1.73	2.20	2.73	6.95	13.73
Other costs per acre 2/	Dollar	205.16	154.36	121.33	81.59	58.99	44.79	35.25	15.27	11.01
United States:										
N-P-K	Lb./acre	269-59-144	226-50-121	191-43-103	137-31-73	94-22-51	60-15-32	30-9-17	---	0-0-0
Crop production per acre	1960-64=100	213	203	192	171	150	128	107	---	80
Substitution NPK for land 1/	Acre/ton	1.20	1.58	2.00	2.99	4.27	5.98	8.35	---	13.20
Other costs per acre 2/	Dollar	84.56	61.45	46.84	29.83	23.56	15.89	12.77	---	10.74

1/ Acres required to produce crops equal in value to the value of product added through use of a ton of NPK applied at the indicated rates.
2/ Variable costs (excl. fertilizer) at which use of the indicated rates of NPK would result in equalizing marginal returns to all variable inputs.

Table 7.--Expenditures for fertilizer to obtain projected 1980 needs at rates for different marginal returns, compared with 1960-64 expenditures, by regions, United States 1/

Region	1960-64 use: Marginal return	1960-64 use: Expenditure	Marginal return: $1.00	Marginal return: $1.25	Marginal return: $1.50	Marginal return: $2.00 2/	Marginal return: $2.50 2/	Estimated 1964 expenditure for fertilizer
	Dollars	1,000 Dollars	1,000 Dollars	1,000 Dollars	1,000 Dollars	1,000 Dollars	1,000 Dollars	1,000 Dollars
				Current prices				
Northeast	1.98	168,542	494,629	407,083	326,055	150,036	(168,542)	113,003
Lake States	2.99	171,161	671,907	590,548	516,019	396,993	284,422	126,737
Corn Belt	1.60	599,956	2,446,231	1,740,440	971,349	(599,956)	(599,956)	442,267
Northern Plains	7.30	119,036	597,316	548,190	508,710	447,178	447,178	113,158
Appalachian	2.85	286,822	966,647	856,661	764,985	613,197	613,197	169,717
Southeast	1.68	266,392	635,253	502,280	367,997	(266,392)	(266,392)	200,918
Delta States	4.86	124,358	382,794	348,508	321,182	277,030	277,030	88,373
Southern Plains	2.58	123,621	718,949	610,919	516,903	341,676	341,676	102,988
Mountain	4.45	87,053	501,738	450,348	405,702	338,514	338,514	59,195
Pacific	4.37	224,238	1,065,754	956,435	866,264	727,903	727,903	149,050
United States	2.50	2,171,179	8,481,218	7,011,412	5,565,166	4,158,875	4,064,810	1,565,406
				Projected prices				
Northeast	2.76	106,888	379,198	351,198	288,751	214,381	141,903	---
Lake States	4.02	122,743	520,226	471,392	421,024	348,421	288,302	---
Corn Belt	2.19	403,920	2,175,783	1,728,932	1,397,477	704,343	(403,920)	---
Northern Plains	11.13	53,253	414,493	384,610	360,342	322,975	295,264	---
Appalachian	4.62	144,866	611,649	554,877	506,738	432,113	372,246	---
Southeast	3.19	155,908	552,474	487,725	433,869	348,604	266,617	---
Delta States	7.34	74,381	273,840	251,059	233,835	206,868	186,210	---
Southern Plains	3.63	79,697	549,889	483,090	429,564	339,066	261,946	---
Mountain	6.57	57,364	357,803	325,891	301,429	260,584	228,603	---
Pacific	6.60	130,859	750,106	686,867	632,958	550,411	486,704	---
United States	3.67	1,329,880	6,585,460	5,725,643	5,005,988	3,727,765	2,931,715	---

1/ Expenditures reflect different acreage needs depending on rates per acre and on marginal return to fertilizer.
2/ Figures in parentheses are expenditures needed at 1960-64 average rates because returns indicated in column headings are higher than at the point of no application.

Fertilizer expenditure per dollar value of crop production increases as the intensive margin of use is approached. Here, progressively more fertilizer is needed to obtain each increment of production. Therefore, expenditures per dollar value of crop production are greater at high rates of application at the current (higher) fertilizer prices.

But at lower rates of application, increments of production are larger so that the reduction in crop value due to the lower projected crop prices is greater than the reduced fertilizer cost per unit of application. Hence at low rates of application, the fertilizer cost per unit value of crop production is higher at projected than at current prices. The combined effect of projected lower crop and fertilizer prices at different rates of marginal return to fertilizer is shown in table 8.

Table 8.--Fertilizer expenditure per dollar value of crop production to meet projected 1980 needs at current and projected crop and fertilizer prices, U.S. average

Marginal return to fertilizer (dollars)	Aggregate fertilizer expenditure per dollar value of crop production	
	Current prices	Projected prices
	Dollars	Dollars
1.00	0.302	0.277
1.25	.250	.241
1.50	.198	.211
2.00	.148	.157

It appears that the projected crop prices would require a substantial reduction in fertilizer price to maintain current fertilizer cost per dollar value of crop production. Projected fertilizer prices would allow for some gain in this regard for farmers who use relatively high rates, but would fall somewhat short of maintaining the current relationship for farmers who apply average, or below average, rates per acre and obtain relatively high marginal returns.

A Note on Liming Materials

The level of farm technology greatly affects the profitability of fertilizer. In some areas, inadequate liming practices may be a major restriction. The greatest use of liming materials occurred during the 7 years from 1946 to 1952. During this period, about 28 million tons were distributed annually, or 27 percent above the average of the 11 succeeding years through 1963. The average rate of application per acre of cropland in the earlier period was 0.74 ton; for the 11-year period ending 1963, only 0.58 ton.

With higher rates of fertilizer accompanied by higher yields per acre in recent years, the lag in use of liming materials may eventually act as a deterrent to future yield increases in some crops and areas. In addition, the trend to liquid fertilizer and to higher analysis solid materials means that less lime, as a component of carrier-materials for fertilizer, is finding its way to the soil.

Since 1960, however, there has been some increase in the use of liming materials. But the quantity used in recent years is about 5 million tons less than that used in 1947 when a record amount of 30 million tons was reported.

About 55 million tons of liming materials are projected for 1980 (table 9). This figure was obtained by relating the index of crop production per acre to tons of liming materials per acre from 1960. Such a tonnage might well be needed to complement projected gains in fertilizer use if potential yield responses are to be obtained.

Table 9.--Projected 1980 use of liming materials compared with 1960-64 average use, by region, United States

Region	Projected 1980	1960-64 average
	1,000 tons	1,000 tons
Northeast	4,510	2,563
Lake States	5,186	2,150
Corn Belt	25,932	10,839
Northern Plains	1,610	536
Appalachian	10,000	4,420
Southeast	3,562	1,695
Delta States	2,270	1,016
Southern Plains	1,448	450
Mountain	83	4
Pacific	556	124
United States	55,157	23,797

Some crops respond directly to lime; the degree of response depends on the nature of the crop, or the extent to which the soil is deficient in lime. But there is also a general benefit of secondary nature because of the influence of lime on the physical and biological condition of some soils.

PROJECTIONS IN A CLIMATE OF TECHNOLOGICAL CHANGE

The projections contained in this analysis, or others that may be drawn from it, are contingent upon all of the economic factors on which projected 1980 crop production needs are based. In addition, unpredictable technological developments could materially alter projections made at any time.

New crop varieties are being developed. If plant breeders should accomplish in the hard and soft winter wheat areas, only half of what Gaines wheat appears to offer in the Pacific Northwest, a projected index of crop production per acre by 1980 might seem modest within a few years. Correction of iron deficiencies in some important grain sorghum areas, or of zinc deficiencies in parts of the Western Corn Belt, could do much to alter yield response to fertilizer and increase the aggregate crop response to wider adoption of improved technology. Correction of zinc deficiencies has in specific instances greatly increased corn yield response to phosphorus. If these deficiencies prove to be extensive, their correction could also alter the ratio of P to N and K that has been projected in this analysis. Correction of known sulfur deficiencies in some areas would materially change the outlook for fertilizer use and crop yields. Research in the Southeast indicates a greater potential for use of fertilizer on soybeans as a result of correcting molybdenum deficiencies.

On the less optimistic side, there is the constant need for protective research to combat new plant diseases and insect pests, as well as to lay the groundwork for technological progress on the farm. But objective economic analysis of technical research, that has been adequately oriented toward aggregative problems, can indicate optimum use of resources to meet output needs. The dynamics of ever-changing technology call for newly conceived research and periodic economic analysis if projections are to be useful guides to farmers, to suppliers of farm inputs, and to persons responsible for making general policy decisions.

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Procedures

1. Projecting relationships between crop production per acre and rates of fertilizer applied per acre.

Indexes of crop production per acre for each region and for the United States for 1960-64 were used as independent variables, with indexes of rates of N per acre as the dependent variables. (As described in the text, judgment estimates were made of the quantity ratios of P and K to N at the different calculated levels of N associated with specified indexes of crop production per acre.)

In the equation $Y = a + bx$, x is a specified index of crop production per acre and Y is the calculated index of N applied per acre based on the relationship between these two indexes for 1960-64. This calculation was made for each of several indexes of crop production per acre up to 200.

The Y values were converted to pounds of N per acre by multiplying them by the 1960-64 average rates of N per acre. These rates for each of a series of indexes of crop production per acre, times the acreage required to meet projected 1980 crop production needs at that point, resulted in the total quantity of N associated with that index of crop production per acre and acreage requirement. Quantities of P and K were then calculated, using estimated ratios of these elements to N. From this, a series of indexes of crop production per acre and corresponding rates (pounds) per acre of N, P, and K was computed.

Pounds per acre of N, P, and K were then plotted coordinate with indexes of crop production per acre, the former on the abscissa and the latter on the ordinate. This provided a graphic method of developing parameters of a fertilizer-index of crop production per acre equation.

2. Calculating parameters of the yield equation.

The exponential equation $Y = M(f^x)$ was used in developing the economic relationships. In this equation Y = the index of crop production per acre, M = the theoretical maximum value of Y, and f^x is the ratio of Y to its maximum value at any rate of application.

As the ratios of P and K to N had been previously estimated in a fixed pattern for this analysis, the combined rates of these elements were first plotted on the abscissa against the corresponding indexes of crop production per acre calculated as described. The 1960-64 average pounds of NPK per acre are coordinate with the index of crop production per acre = 100. A graphic approximation to a least-squares fit was obtained, using the points coordinate with a series of higher indexes of crop production per acre, up to 200. Three readings were taken--one at pounds of NPK per acre at the index of crop production per acre = 100, one at pounds coordinate with the index of crop production per acre = 200, and one at exactly the midpoint between the two. From these readings, parameters of the yield equation were developed approximately as has been described in an earlier publication (4).

Pounds of N, P, and K separately were then plotted coordinate with the same indexes of crop production per acre as were used when all three nutrients were combined. Graphic approximation to a least-squares fit was obtained as before, for each individual nutrient curve. As rates of the three nutrients increase simultaneously with increases in the indexes of crop production per acre, M for each individual curve is necessarily the same as on the curve for NPK combined. Pounds of N, P, and K were each read coordinate with crop yield indexes of 100 and with the midpoint index as read from the curve of all three nutrients combined. This information, together with acceptance of the same value of M on each separate curve as was calculated from the curve combining the three nutrients, provided a basis for calculating parameters needed for the individual nutrient curves.

3. Calculating values for tables 2 and 6.

Expression of results in monetary terms requires an expression of M in the yield equation as quantity of crop production per acre times price. First, the base period value of the latter is obtained as the sum of the individual average crop quantities for the base period times their respective base period prices. The resulting value represents the base yield in dollar terms. This, times the calculated maximum index of crop production per acre, is the maximum yield in absolute terms. The calculated value of yield at any rate of application multiplied by any price relative to 100 represents the value of crop production per acre at that rate of application and price.

As projected 1980 crop production needs assumed lower crop prices than the base period, the estimates in table 6 reflect lower crop values per acre (as well as lower fertilizer prices) than those in table 2. Details of calculating yields at specified rates of application, or at specified marginal returns, have been published (4).

4. Calculating fertilizer-land substitution relationships and economic minimum rates of application.

The expression f^x in the yield equation is $1 - R^x$, where R is the ratio of successive increment in yield and x is the number of units of application, which as an exponent of R represents the power to which R is raised by a specified application. The Spillman table of $1 - R^x$ values, where R is specified at 0.8, is used. The size of unit such that R = 0.8 is the parameter reflecting the rate of response, and is easily computed.

The number of acres for which a ton of NPK substitutes may be computed in two steps. First, C, the total variable cost at which a rate of application would result in equal marginal returns to all variable costs, is calculated as:

$$\frac{Px\,(1 - R^x)}{R^x\,(\ln R)} = C$$

In this, P^x is the cost of a unit of application (here such that R = 8) and ln R is the natural log of 0.8. In practice, the value of C at any rate of application is more simply determined as gross return per acre divided by marginal return per dollar cost of fertilizer.

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The second step in estimating the fertilizer-land substitution relationship at any rate of application involves the cost of a unit ton of NPK. The size of unit (pounds) is indicated as u_x, and this times the cost per pound as Px. The sum of the 3 Px values (for NPK) divided by the sum of the u_x values is the cost per unit pound, which times 2,000 is the cost per unit ton, designated as S. Then S/C represents the number of acres from which the value of product is equal to the marginal value product of a ton of NPK.

The item "other cost," in tables 2 and 6 and figure 1 with accompanying discussion, is C minus the fertilizer cost at the corresponding rate of application needed to satisfy the specified marginal return to fertilizer.

5. Acreage and fertilizer combinations for different levels of crop production per acre--figures 2 to 12.

Several combinations of cropland acreage and tons of NPK for meeting projected 1980 crop production needs were used in constructing figures 2 to 12 (table 4). For a particular value of total crop production (here the sum of projected 1980 crop quantities times their projected prices), the acreage requirement diminishes as the index of crop production per acre rises. The 1960-64 average tonnage of a nutrient in figures 2 to 12 is coordinate with the crop production per acre index of 100 and the cropland acreage required to meet projected 1980 needs at the average level of technology for 1960-64.

The rate per acre increases with increases in the index of crop production per acre. Each successively higher rate per acre multiplied by the acreage requirement at a specified index of crop production per acre results in the estimated total quantity of a nutrient required at that point.